Recovery Plan
for
Plum Pox Virus (Sharka) of Stone Fruits

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This recovery plan is one of several disease-specific documents produced as part of the National Plant Disease Recovery System (NPDRS) called for in Homeland Security Presidential Directive Number 9 (HSPD-9). The purpose of the NPDRS is to insure that the tools, infrastructure, communication networks, and capacity required to mitigate the impact of high consequence plant disease outbreaks are such that a reasonable level of crop production is maintained.

Each disease-specific plan is intended to provide a brief primer on the disease, assess the status of critical recovery components, and identify disease management research, extension and education needs. These documents are not intended to be stand-alone documents that address all of the many and varied aspects of plant disease outbreak and all of the decisions that must be made and actions taken to achieve effective response and recovery. They are, however, documents that will help USDA guide further efforts directed toward plant disease recovery.

Executive Summary

Plum pox virus (PPV) is an important disease of the stone fruits plums, peaches, nectarines, apricots and almonds. The disease has existed in Europe for many years but was first found in the United States in 1999 and in Canada in 2000. The disease affects fruit quality and yield threatening the productivity and economic profitability of the nation's stone fruit industry. Several years of a national survey of stone fruit orchards has found the disease is limited in the United States to a small region in south central Pennsylvania. Intensive tree by tree surveys for PPV and aggressive orchard eradication efforts from 1999 through mid 2006 have resulted in the removal of over 1500 acres of stone fruit trees from Pennsylvania. Some individual growers in the infected PPV area have lost all of their peach and nectarine production, ending decades of stone fruit production on their family farms.

Since initiation in 1999, orchard surveys and eradication efforts have been a model of cooperation between growers, extension educators, university and government researchers and local, state, and federal government regulatory agencies. Funding programs approved by state and federal governments have facilitated needed grower and extension education about plum pox virus, yearly orchard surveys, quarantine and eradication programs, research and grower compensation for removed acreage, as well as research to aid control. As a result, the PPV virus level in PA orchards has decreased with each year of survey and eradication, an indicator of the potential for the ultimate success of the PPV program. At the farm level, early successes have resulted in several quarantine zones being removed beginning in 2004 after 3 consecutive years of negative survey and testing results for the virus. Grower cooperation has been and remains high throughout the PPV eradication efforts from 1999 through 2006. There is no evidence that PPV infected plant material has entered the distribution system in the United States since 1999. However, stone fruit trees infected with PPV were found in 2006 in Michigan and New York states.

Some concerns remain among growers and university and government cooperators in the PPV eradication effort that may affect the final success of the PPV eradication effort.

- New and more reliable testing techniques are needed to reduce the potential for a false reading of leaf material due to variables in sampling, testing and environmental influences.
- Additional research is needed to address the many questions that remain concerning the virus and its spread to stone fruit trees and to develop PPV-resistant stone fruit cultivars for future distribution.
- There is concern that the government expects PA survey costs to decrease over time when, due to replanting in quarantine areas, survey costs will increase.
- The elimination of extensive sampling of stone fruit production regions outside of PA areas ignores areas of real potential spread and threat to national stone fruit production.

The PPV eradication effort is on course to successfully eliminate PPV from United States stone fruit industry. However, the PPV survey must be continued for several years in order to ensure the eradication of PPV.

There is a brief window of opportunity for the eradication of PPV. If we do not take advantage of that window with careful, sensitive and redundant survey, then eradication will not be achieved. To succeed with eradication, survey must be repetitive as well as sensitive. The survey must be repeated over a number of years, even when results are negative and there is pressure to end the eradication effort.

Contacts

Don Albright, USDA APHIS PPQ, 717-241-0705, Don.I.Albright@aphis.usda..gov
Ruth Wellivar, PA Department of Agriculture, 717-772-5222, rwelliver@state.pa.us
Fredrick E. Gildow, Penn State University, Research, 814-863-3206, feg2@psu.edu
James W. Travis, Penn State University, Extension, 717-677-6116, jwt2@psu.edu

Contributors

Penn State University

F. E. Gildow, Professor of Plant Pathology
J. Halbrendt, Associate Professor of Plant Pathology
J. Harper, Professor of Agricultural Economics
L. Kime, Research Assistant Agricultural Economics
W. Kleiner, Extension Educator
G. Krawczyk, Research Associate, Entomology
J. W. Travis*, Professor of Plant Pathology
* Chair and corresponding author (jwt2@psu.edu)

PA Department of Agriculture

A. Echard, Plum Pox Field Survey Coordinator
L. Forer, former Director, Bureau of Plant Industry
E. M. Haas, Director, Bureau of Plant Industry
T. Jones, Plum Pox Laboratory Technician
R. Lehman, former Plum Pox Field Survey Coordinator
N. S. H. Richwine, General Survey and Mapping Coordinator
J. Stimmel, Entomologist
K. Valley, Chief, Plant Protection Division
R. Welliver, Plum Pox Laboratory Coordinator

USDA APHIS PPQ

D. Albright, National PPV Operations Director, USDA APHIS PPQ
C. Ball, former Operations Support Officer, USDA APHIS PPQ
J. M. Miller, former PPQ Officer, USDA APHIS PPQ
G. Gamester, PPQ Officer, USDA APHIS PPQ
M. Weldon, PPQ Officer, USDA APHIS PPQ
S. Musser, PPV Administrative Officer, USDA APHIS PPQ

Recovery Plan
for
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I. Introduction

Plum pox virus (PPV) is a serious disease of stone fruits worldwide. The disease was first observed in Bulgaria in 1915 and given the name Sharka which is Slavic for plum pox. PPV has become an important disease problem across Europe where it causes significant economic loss due to a reduction in fruit quality and yield and due to premature tree death. PPV was found in South America in 1992 and North America in 1999.

In the United States, PPV was only found in Pennsylvania beginning in 1999. PPV was identified in Canada in 2000. The strain of the virus identified in PA, known as PPV-D infects stone fruits (*Prunus*) including plum, peach, nectarine, almond and apricot as well as many related ornamental *Prunus* species. Cherry is not known to be infected by this strain of the virus. How PPV was brought into PA has not been determined, however, infected plant material for propagation is considered the most likely mode of introduction. Once introduced into an area, the virus spreads through aphid feeding.

II. Symptoms

Plum pox virus causes several different types of symptoms on different parts of the fruit tree and at different times of the growing season. PPV symptoms are generally similar on stone fruits (peaches, nectarines, plums and apricots). Symptoms do not normally begin to appear on the tree until about three years after the infection takes place. While visual symptoms can be very useful for diagnosis, the absence of symptoms is not a guarantee of disease free fruit trees, as many infected trees or cultivars may remain symptomless. The only sure method of detecting PPV is through laboratory screening tests. The PA eradication program has therefore focused on detection through leaf collection and analysis in the laboratory rather than relying on PPV symptoms expressed in the orchard.

<u>Blossoms.</u> The first symptom that may be observed is blossom streaking. Characteristic color streaking of peach flower blossoms in association with PPV infection has been reported in some European PPV regions but not others.

This blossom streaking symptom has been observed only once in Pennsylvania although disease level is so low in PA orchards and bloom time is so short that it makes searching for this symptom impractical. It would be difficult for the orchard observer to detect blossom streaking since peach blossoms are often very showy making detection of small differences in coloring difficult to detect and since streaking is reported to vary even from petal to petal or tree to tree.

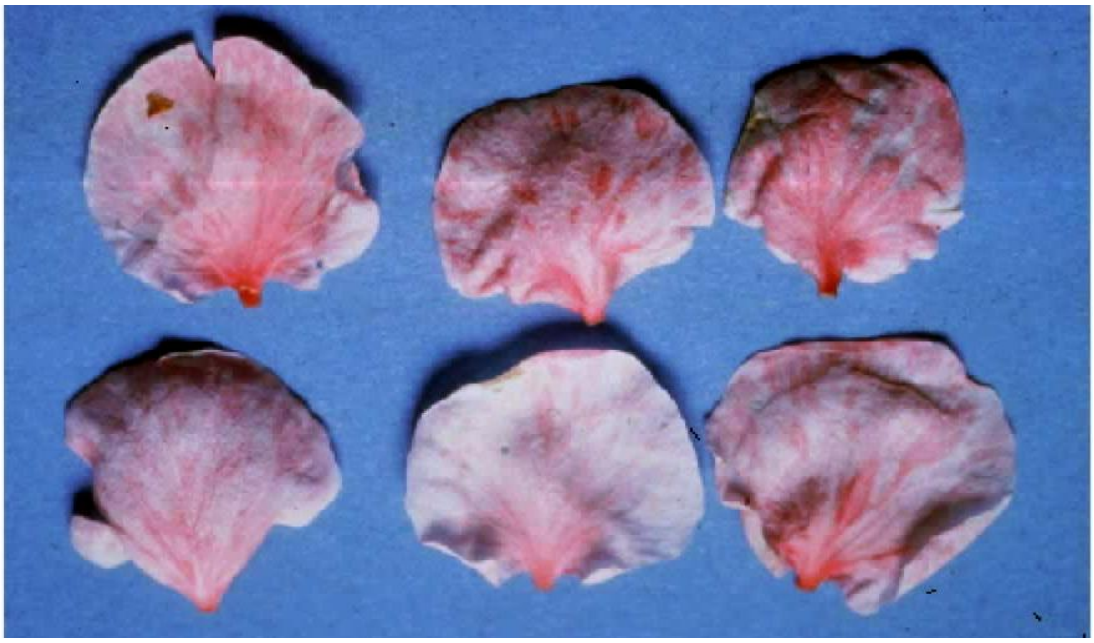

Figure 1. Peach blossom streaking caused by PPV. Courtesy of J. B. Quiot, Southern France.

Leaves. Several types of symptoms may occur on leaves. PPV may cause leaves to have faint light green to yellow ring spots or halos about the size of a pencil eraser or smaller scattered across the leaf. Leaves may also exhibit a yellow netting pattern which is often accompanied by veins that are lighter green than normal to yellow in color. Leaves may be distorted or twisted as a result of infection.

Figure 2. Leaves with yellow netting and distortion caused by PPV. Courtesy of J.W.Travis, Adams Co., PA.

The location of the PPV leaf symptoms is also important. Symptoms appear on the first leaves to develop on new infected shoots in the spring. These leaves occur at the base of new shoots and if symptoms are present, will often be visible until temperatures reach 85 to 95 degrees F in late spring and summer at which time the PPV symptoms fade and are no longer visible. When looking for PPV leaf symptoms, scouts observe the leaves on the lower (basal) 1/3 of the shoot since leaves that are produced after early spring do not show symptoms even if the shoot is infected and more basal leaves do have PPV symptoms. Not all infected branches and shoots on an infected PPV tree produce leaves with PPV symptoms. Symptoms may be more pronounced and more widespread through the tree in younger trees than old, and in plum more than peach.

Fruit. While the blossom and leaf symptoms can be easily missed, it was the bold yellow ring spots on the red skins of peach fruit of the cultivar Encore that first made the PA fruit grower who found PPV aware that there was an unusual and serious problem with his fruit. Some stone fruit cultivars show no symptoms after infection while others like Encore peach display pronounced PPV symptoms about 3 years after the tree is infected. At first only a few fruit show the symptoms but eventually nearly all the fruit on the tree are spotted and the symptoms become easier to see as the fruit ripens.

Figure 3. Yellow halos and ring spots on peach fruit caused by PPV. Courtesy R. Welliver, Adams Co., PA.

The yellow halos on the fruit are only ‘skin-deep’ and are removed with the skin, however, due to the blemish, the fruit is worthless for fresh fruit sales. The symptoms become easier to see as the fruit ripens. On some fruit cultivars, the fruits are abnormally formed and distorted by PPV infection. Some apricots also have distinct PPV yellow halos on the seeds. Premature fruit drop that occurs as the fruit are beginning to ripen is

another devastating symptom of PPV infection in fruit trees. The ground under PPV infected fruit trees may be covered with fruit lost just before harvest.

Fruit Trees. The final and most devastating symptom to fruit growers and fruit production in a region is premature tree death. Estimates from Europe indicate that in areas where PPV is not eradicated, the fruit grower can expect a 5% per year tree death from the disease. The impact of a 5% loss over several years is easy to calculate. A ten year old fruit orchard which should be productive for 25 years, will suffer 50% tree loss in the first ten years. Replanting the trees that die as a result of PPV is not a practical solution due to complications from root disease replant problems and the shading of young trees that occurs in a mature orchard.

III. History and Spread of PPV in Pennsylvania

PPV is spread naturally by aphid vectors and through graft transmission as a human activity. There is general agreement that the original source of PPV to the United States and more specifically PA occurred through infected plant material. However, the actual incident and location of the original infection has not been conclusively identified. Based on initial finds and expected follow-up spread by aphids, the original orchard infection probably occurred in northern Adams County, PA in or before 1991. PPV was first positively identified in September of 1999 in Pennsylvania by the PA Department of Agriculture and verified by the USDA. However, as early as 1996-97 an Adams county fruit grower had recognized unusual spotting symptoms developing on his Encore peaches and had tried unsuccessfully to learn the cause. Because Plum Pox had never occurred in the U.S, very few industry personnel or academic researchers associated with the stone fruit industry were familiar with PPV symptoms and the disease remained unreported. In 1999, after seeing the symptoms for several seasons and with no success in learning the cause, the grower sent infected fruit to a New Jersey fruit extension specialist who had seen PPV in Europe and suspected PPV. Extension personnel from PA simultaneously contacted the PA Department of Agriculture, who forwarded fruit to the USDA quarantine facility for definitive identification.

Once introduced in an area the primary risk of spread of the virus is by aphids from tree to tree and through distribution of infected nursery plant material. Initially nursery stock was believed to be at risk of having spread PPV infected plant material since fruit bud wood had been cut by two PA commercial nurseries from orchards in the area where PPV had been identified. However after extensive nursery stock surveys and tracking new orchards established from nursery material over the previous several years, it became evident that the local nurseries did not spread PPV through the sale of infected nursery material. The absence of nursery spread was very fortunate and one of the most important factors that will contribute to the ultimate success PPV eradication in the United States. Although every state with a stone fruit industry was surveyed intensively for 3 years, no other infected PPV orchards have been found outside of Pennsylvania. Through 2005, only the three highest risk states adjacent to PA continued surveying for PPV. In 2000, two of the commercial nurseries in the quarantine area moved their stone

fruit plant propagation to a near-by state where PPV was not found to prevent any additional risk of spread from the nursery trees.

Following the initial introduction of infected planting material to PA, aphids spread the virus from the original infected orchard to adjacent orchards. Aphids are poor flyers, so the spread occurred in the direction of prevailing wind currents. Several species of aphids common to Adams county PA have been identified that are capable of spreading the virus. However, recent research indicates that aphids are not efficient carriers or transmitters of the virus. Fortunately for local and US fruit industry, aphid spread of the virus was at a slow rate and did not progress far from the original PPV infected orchard. This has permitted the eradication efforts to concentrate on a limited geographical area greatly increasing the potential for success. In contrast, PPV has become endemic in extended fruit producing regions in France and Spain, preventing eradication of infected trees resulting in the continued spread of the virus disease by aphids. This has resulted in devastating losses in production and profitability to the fruit industry of these countries. In some regions, alternative crops were required to replace stone fruit production.

Following the initial detection of PPV in Adams County, PA, there was concern that aphids might spread PPV into wild plant hosts including several common weed species. If PPV were to become established in indigenous native plants and weeds, eradication would become impossible. Fortunately, extensive surveys conducted annually over a 6 year period of potential wild plant hosts have identified no wild plant species infected with the PPV. It was also recognized early that if infected fruit had been culled from local PA fruit packing lines and dumped in outside cull piles that aphids may be capable of spreading the virus from the infected fruit to healthy near-by stone fruit orchards. Some circumstantial evidence suggested that this could have happened on a small scale. For this reason, steps have been taken to prevent the potential spread from fruit culls.

IV. Economic Impact and Compensation

Stone fruit production is an important part of Pennsylvania's and United States agricultural economy. In 1999, the yearly value of production of peaches, nectarines, plums, apricots, and almonds nationally was approximately $1.8 billion. PA ranks fifth nationally in peach production with about 6,500 acres in 1999 (PA Agric. Statistics Service). In 1999, about 44% of the PA stone fruit acreage was located in Adams County were PPV was found. The annual value of PA stone fruits was approximately $22.3 M in 1999.

Soon after PPV was discovered in Adams County PA and state and federal destruction orders were issued, growers began working with local and state Penn State Cooperative Extension personnel to develop an indemnification program compensating growers for the lost production of trees that were destroyed due to PPV. The first orchards were removed prior to any guarantee of compensation programs being approved by state or federal governments. This evidence of the high degree of grower cooperation in the eradication of PPV from the United States has been demonstrated throughout the PPV eradication process.

The Pennsylvania legislature led by local state legislators responded very quickly by enacting the Drought, Orchard, and Nursery Indemnity and Flood Relief Act on December 13, 1999. The act provided $ 2 M ($3.1 M –May 2000) for indemnification and removal and destruction of trees. The state funding has been renewed each year since its initiation.

The indemnification program is based on the value of the tree that takes into account the remainder of the average life of a productive commercial orchard in Pennsylvania. A grower/extension formula for compensation was slightly modified and adopted by the USDA in November 2000.

The destruction orders given to growers provides them10 days to begin to remove the trees. There has been much appreciated flexibility by PDA and USDA in allowing growers to harvest their crop before removing the trees if harvest occurs within a few weeks of the destruction order. Some growers harvested the crop and removed the trees immediately after receiving the destruction orders while others removed the trees with a full crop on the trees. Growers are compensated for tree removal, pest control prior to removal, site preparation, cover crops establishment and estimated orchard productivity over the remainder of the life of the orchard. The federal government passed legislation to pay $15M in PPV indemnity payments as part of the Agricultural Risk Protection Act in June 2000. A payment program was published in the Federal Register in September 2000. The USDA has provided 85% of the indemnification funds while PDA is providing 15% of the funding. To date (2006), over 26 M dollars have been paid to growers for indemnification from state and federal sources. Some of the first growers to remove trees in the winter of 2000 were still not permitted to replant in the spring of 2006. However, the quarantine has been removed in some areas and growers have been permitted to replant stone fruits with the last two years.

In 2000, Penn State Cooperative Extension performed an economic impact study that determined that the economic loss to the community, not including growers for every 1000 acres of trees removed would be $1.6M per year. This impact is in jobs, taxes paid to school districts, townships and the county. It also accounts for the effect on equipment dealers, fuel suppliers and suppliers to the growers. Nearly 1500 acres of stone fruits have been destroyed in PA due to PPV through the fall of 2005, 6 years since PPV was first identified. Therefore the approximate cost to the community, excluding the fruit growers has been about $ 14.4 M over the last 6 years.

V. Surveys and Detection

Summary of Past Survey Results

Surveys began in the fall of 1999 soon after PPV was positively identified in an Encore peach orchard in Adams County, PA. After testing by the PA Department of Agriculture and the USDA-APHIS-PPQ laboratory in Beltsville, MD the peaches were proven to be infected with the D-strain of plum pox virus. State and federal quarantines were placed on townships in PA where PPV was detected permitting no replanting or removal of

stone fruit seedling or vegetative plant material from the area. When PPV-infected trees for PPV were found it required the removal of whole orchard blocks as well as residential and wild *Prunus* trees.

Figure 4. Removal of *Prunus* trees. Courtesy of J.W.Travis, Adams Co., PA.

In 2001, the eradication zone was extended to include a 500 meter buffer around infected trees and orchards. In 2000 surveys were conducted in all the major stone fruit growing states (MI, NY, SC, NC, MD, CA,) with the most concentrated efforts occurring in PA. Fortunately for the US stone fruit industry, PPV was not wide-spread being detected only in a small fruit production region in southern PA a few miles north of Gettysburg. Commercial orchard samples are tracked by a number referring to the county, grower, and orchard block using barcode tags in the orchards and on leaf sample bags for identification. A hierarchical survey protocol (two, eight leaf samples from 25% of the orchard trees) was followed for areas more than 5 miles from quarantined areas. Within quarantine areas, recently rescinded quarantine areas and areas up to 5 miles from a quarantine zone sampling, every tree was sampled at either 4 or 8 leaves per tree depending on the proximity of the orchard to a quarantine zone. Tissue samples are collected from commercial orchard trees, residential properties, nursery and budwood source trees, sentinel trees and wild trees. The sampling goal by 2005 was to sample every tree in commercial orchards and residential properties in the quarantine zones and surrounding areas on a yearly basis and to sample *Prunus* orchards outside the quarantine area on a three year rotation. Sampling generally begins in early May and concludes the end of August. A total of 213,005 leaf samples were collected from commercial orchards in 2005. Initially, all stone fruit orchards in the state of PA were surveyed collecting

samples from every fourth tree in orchard outside the quarantine area with every tree sampled inside the quarantine zone. Over the next 6 years, the quarantine zone was extended to portions of 3 other counties adjoining Adams County. None of the additional trees found to be positive for PPV were more than 50 miles from the original PPV quarantine zone.

In 2001, the first PPV positive trees were found outside commercial orchards on a residential property. Extensive surveys of stone fruit trees in residential properties were also systematically carried-out in the PPV in the quarantine areas and within 5 miles of the quarantine. Leaf samples consist of eight leaves from each identified *Prunus* on the property. In 2005, 66,478 residential properties were visited with 50,609 trees sampled for PPV. From 2001 through 2005, several positive PPV homeowner trees were identified which in some cases expanded the quarantine area and resulted in additional commercial orchard removal.

After six years of sampling and testing, no plum pox virus has been found in the United States outside of the quarantine zone in PA and fortunately PPV did not enter the United States nursery distribution system. The PA quarantine once included about 250 square miles but has been reduced in size due to 3 consecutive years without a positive to about 200 square miles. In 2005 and by mid season 2006, only a few positive trees in commercial orchards and residential trees were found. From 1999 through 2005, 1,598 acres of commercial orchard and trees on approximately 190 residential properties had been destroyed. Commercial fruit growers and the community have made a significant sacrifice to rid the United States of this disease.

Nursery production of *Prunus* has been suspended in, 1.) quarantine zones, 2.) within areas 11.5 km from a positive tree found in the previous three years, and 3.) quarantine areas for three years after the primary quarantine has been rescinded. In addition, propagators of susceptible *Prunus* within PA must have all bud wood sources tested for PPV. Due to these restrictions, *Prunus* nursery production is limited to areas outside Adams County and in some cases has been moved to nearby states. In 2005, four *Prunus* propagation nurseries, located in and outside PA, were tested with all nursery and budwood sources testing negative for PPV.

PPV was detected in Canada in the Niagara Peninsula in 2000. There were concerns that the stone fruit growing areas in Michigan and NY near Ontario could also be infected with the virus. The region was intensively surveyed from 2000 through 2005 with no trees testing positive for PPV. In 2006, PPV was found in both Michigan and New York State. The virus was found in 2 locations in Niagara County, New York on July 10, and August 21, 2006. A plum tree was also found to be infected with PPV at the Southwest Michigan Research and Experiment Center on August 11, 2006. Extensive testing followed these 2 finds but no additional stone fruit trees were found to be infected with the virus.

Detection

Orchards were sampled utilizing a hierarchical grid (Gottwald, USDA, 2000). In PA during 2000 and 2001, one-fourth of all trees in an orchard were sampled in a specific pattern, with the quadrant being sampled randomly chosen each year. Trees were marked with a bar code which identified the grower and tree number. Four leaves were collected from each of the four compass points on the tree. All 16 leaves were placed into a plastic bag receiving the same bar code identification as the tree. This permitted accurate identification of each tree in the event that a positive result triggered additional sampling to affirm a positive PPV tree. Leaf samples were placed into plastic bags and placed in ice chests to be taken to a cold room storage facility the same day. Samples were systematically tested using first a serological technique known as ELISA followed by PCR if a positive result occurred from ELISA. During 2002, the third year of sampling in PA, all the trees in the quarantine areas were sampled but continuing the hierarchical sampling scheme for the remainder of the state outside the quarantine area. A sentinel tree system was established in the quarantine area in 2002. In 2003, the sample size per tree in the quarantine zone was increased to 8 leaves per tree and the first positive for PPV was found in a nursery late in the season.

A sentinel tree program was begun in 2002 as a warning system for PPV in quarantine zones. The sentinel trees are highly susceptible trees to PPV and are useful for detection since many of the *Prunus* trees in a quarantine zone have been removed. By 2005, 197 sites with over 500 sentinel trees were established in critical PPV areas. Each tree is sampled twice a year and to date all sentinel trees have tested negative to PPV. In a related effort, regrowth root sprouts from removed trees and seedlings at stone fruit dump sites have been sampled, tested and found negative for PPV.

Figure 5. Root sprouts after tree removal. Courtesy of J.W.Travis, Adam Co., PA.

Growers have been instructed to control root sprouts after tree removal and eliminate fruit cull piles to reduce the risk of these sites serving as a source for PPV.

Weeds have been surveyed for 6 years in the vicinity of PPV infected orchards. Leaves of weeds and wild trees are sampled weekly during the growing season and tested for PPV. Over the six years, 65,461 samples have been tested and found negative for PPV. Since 2002, 23,498 herbaceous bait plants have been located in PPV quarantine areas and later tested with all found to be negative for PPV.

Monitoring and Identification of Aphid Populations in the Vicinity of PA *Prunus*

Monitoring of aphid populations has been conducted in commercial orchards, residential properties and in sentinel trees beginning in 2000 and continuing through 2006. The project objectives are to identify potential aphid vectors of PPV and determine seasonal variation. In summary, 29 different species of aphids were identified with the fewest number of aphid species occurring in commercial *Prunus* orchards as a result of effective pest management programs. Higher numbers of aphid species were collected on sentinel trees which receive less intense pest management than commercial orchards. Because of higher aphid numbers, the sentinel trees may serve their intended purpose and be the first indicators of PPV resurgence or reintroduction into the area. The peak time for aphid species collection in commercial orchard occurs in late June and July. *Aphis spiraecola,* (picture below*)* the aphid species assumed to be the most significant vector of PPV in PA due to its prevalence in orchards during the growing season and its efficiency as a vector.

Figure 6. Aphid, *Aphis spiraecola*, common vector of PPV. Courtesy of Fred Gildow, Penn State University

VI. References: Educational Program Materials and Research Publications

Hardcopy publications, videos and dedicated web sites were developed soon after PPV was first discovered in PA. The educational programs were developed to educate the US fruit producers of the threat of PPV to the *Prunus* fruit industry, aid in symptom recognition and promote communication between government agencies, university research and extension programs.

Educational Program Materials: Publications/Websites

1. Fact Sheet - Sharka: Plum Pox Virus of Stone Fruits

Released in January 2000, 3 months after PPV was first identified in PA, this publication was the first grower educational literature on the disease. The fact sheet consisted of a 4 color pages providing disease history, symptoms, fruit tree susceptibility, virus characterization, mechanism of spread and information on quarantine and eradication. A 2-page black and white insert was included which provided specific information on the identification, survey results, an indemnity program and plans for control in Pennsylvania.

Prepared by F. E. Gildow, J. W. Travis, J. Halbrendt, Penn State University and R. Welliver, PA Depart. Of Agric.

2. Penn State University Extension PPV Web Sites: Sharka.cas.psu.edu

This web site was available by January 2000. It provided historical information of PPV and color images of symptoms from PA, Spain and France. There were also regular updates on the current status of the PPV eradication program. Growers from PA and across the United States regularly visited the site to stay informed on the status, plans and progress being made in the PPV eradication effort. Educational meetings being planned by extension and the PA Dept. of Agric. were listed on the site. In the first 6 months there were 6872 visits to the site. Many growers commented that this site was one of their primary sources of timely information on the disease.

Supported by J. W. Travis and C. Backman, Penn State University

3. PA Department of Agriculture PPV Web Site: State.pa.us/PA_Exec/Agriculure/plum_pox

Established within the first 6 months of the PPV eradication effort this site provided information on the specifics of current eradication efforts, indemnification programs and informational meetings being organized to provide growers and other interested parties with contacts to state and federal agency representatives. Growers accessed the site on a regular basis to remain informed of the eradication and indemnification programs.

Supported by N. Richwine, R. Welliver, K. Valley, PA Dept of Agric.

4. USDA Plum Pox Fact Sheet

Produced by the USDA in 2000, the fact sheet provides information on history, symptoms, spread and control along with contact information to report infestations.

Supported by USDA-APHIS-PPQ and USDA-ARS personnel

5. Video: Plum Pox Virus in Pennsylvania, April 2000

The 42 min video was released in April 2000 and was distributed to extension educators, fruit researchers and fruit grower organizations across the United States. It was used as an educational tool that provided a history of the disease and symptoms but also the personal accounts of the PA farmers who were most affected by the disease. Researchers, state regulators and extension personnel were also interviewed to provide information on research, survey methods, quarantines and extension educational programs being established to eradicate the disease.

Content Authors: J. W. Travis, F. E. Gildow, J. Harper Producer: J. Dickison
Editor: T. Cherry, Penn State University Extension

6. Plum Pox Virus and Other Diseases of Stone Fruits: A Field Guide

This pocket field guide is 120 pages of color images of PPV symptoms on fruit, leaves and seeds from PA and Europe. It provides explanation of where to look and how to fine symptoms. The guide also provides color images of the differing PPV symptoms between the stone fruits such as peaches, apricots and plums.

There was much concern in the fruit grower community about any marks or abnormal symptoms on stone fruits. It was soon realized that although growers had fact sheets and web sites with symptoms to refer to when evaluating symptoms on the fruit, they had no field-ready guide to easily carry with them to examine and compare symptoms of PPV in the orchard. This pocket guide to PPV and other stone fruit disease symptoms was developed by the second growing season after PPV had first been identified and was used widely by growers and extension educators in orchards.

Developed by J. W. Travis, F. E. Gildow, K. D. Hickey, D. Sammataro, J. Rytter, G. Krawczyk, R. M. Crassweller, R. A. Welliver and N. S. H. Richwine from Penn State University and the PA Department of Agriculture.

7. Robust Research and Rapid Response: The Plum Pox Virus Story. T. R. Alter, J. **C.** Bridger and J. W. Travis. 2004. Journal of Higher Education Outreach and Engagement. 9(1): 131- 140.

The article focuses on the cooperative effort by growers, universities and government agencies to address the plum pox virus problem.

8. Poster of Plum Pox Virus Symptoms on Stone Fruits

The poster displayed color images of PPV on fruit and leaves and was produced in English and Spanish. It was developed for grower use in education of the public and their orchard workers.

Developed by the California Department of Food and Agriculture and USDA personnel

Supporting Research and Publications

Research has been conducted to address some of the key questions regarding PPV spread, insect vectors, virus characterization and host susceptibility. The following is a list of the research manuscripts published or in progress in support of the PPV eradication program in the USA.

1. Plum Pox in North America: Identification of Aphid Vectors and a Potential Role for Fruit Virus Spread. F.E. Gildow, V. Damsteegt, A. Stone, W. Schneider, D. Luster and L. Levy. 2004. Phytopathology 94:868-874.

Results support the hypothesis of secondary PPV spread by indigenous aphids in PA, and suggest that PPV-infected fruit has the potential to function as a virus source for long-distance dispersal.

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2. Aphid (Hemiptera: Aphididae) species composition and Potential Aphid Vectors of Plum Pox Virus in Pennsylvania Peach Orchards. 2005. C. M. Wallis, S. J. Fleischer, D. Luster and F. E. Gildow. J. Econ. Entomol. 98 (5): 1441-1450.

Aphid species communities and seasonal dynamics of the dominant aphid species within PA peach orchards were collected and identified. The most probable significant PPV vectors were identified as *A. spiraecola* and *M. Persicae* in PA peach orchards.

3. Molecular, Ultrastructural and Biological Characterization of Pennsylvania Isolates of Plum Pox Potyvirus (PPV). William L. Schneider, Vernon D. Damsteegt, Fred E. Gildow, Andrew L. Stone, Diana J. Sherman, Laurene E. Levy, Vessela Mavrodieva, Erin Goley and Douglas G. Luster. (In Progress)

The PPV Pennsylvania isolates were characterized by sequence analysis, electron microscopy and biological characterization to determine how these isolates related to their previously studied European counterparts. At the sequence level PPV Pennsylvania (PPV-Penn) isolates were more closely related to each other than to any other D strains of PPV, and isolates from the US, Canada and Chile were more closely related to each other

than to described European isolates. Based on sequence analyses the PPV-Penn isolates exist as two subgroups, suggesting the possibility of multiple introductions.

4. Prunus Host Range of Plum Pox Virus (PPV) in the United States by Aphid and Graft Inoculation. V. D. Damsteegt, R. Scorza, A. L. Stone, W. L. Schneider, K. Webb, M. Demuth and F. E. Gildow. (Submitted for Publication)

Aphid transmission (*Myzus persicae* Sulzer) and bud or chip grafting was utilized to determine which *Prunus* species could function as potential hosts and virus reservoirs. Commercial, ornamental, and wild *Prunus* species were inoculated with isolates of PPV found in Pennsylvania. Thirty-one of 33 *Prunus* species and cultivars tested were susceptible to infection by aphid transmission with 39 of 40 species infected following grafting of PPV-infected bud wood. Results indicate that a wide range of native and ornamental *Prunus* species are susceptible to U.S. isolates of PPV-D

5. Identification of a mutation in the Plum pox potyvirus NIb gene associated with adaptation to pea (Pisum sativum) Christopher M. Wallis, Andrew L. Stone, Diana J. Sherman, Vernon D. Damsteegt, Fred E. Gildow, and William L. Schneider. (submitted for publication)

Plum pox potyvirus (PPV) populations from peaches consistently adapt to herbaceous hosts, characterized by a reduction in time to symptom development, increases in inoculation efficiency and increased titers.

6. NE 1006 Multi-State Program on Plum Pox Eradication and Control

This project was developed to promote communication and collaboration between university researchers and extension educators, government agency personnel and international cooperators. The meetings were held yearly and focused on research, education and the eradication efforts taking place in the United States and Canada.

The most recent NE 1006meeting was held in Ontario, Canada in October 2005.

7. Additional publications relating to PPV eradication in Pennsylvania.

Levy, L., V. Damsteegt, and R. Welliver. 2000. First report of plum pox virus (Sharka Disease) in *Prunus persica* in the United States. Plant Disease 84(2):202.

Hughes, G., Gottwald, T.R., and Levy, L. 2002. The use of hierarchical sampling in the surveillance program for Plum pox virus incidence in the United States. Plant Dis. 86:259-263.

Damsteegt, V.D., Stone, A.L., D.G. Luster. 2001. Preliminary Characterization of a North American Isolate of *Plum Pox Virus* From Naturally Infected Peach and Plum Orchards in Pennsylvania, USA. Acta Hort 550, ISHS: 145-152.

Schneider, W. L. , Sherman, D. J. , Stone, A. L. , Damsteegt, V. D. , Frederick, R. D. 2004. Specific detection and quantification of Plum pox virus by real-time fluorescent reverse transcription-PCR. Journal of Virological Methods 120 (1): 97-105.

Damsteegt, V. D., Stone, A. L., Schneider, W., Luster, D. G., & Gildow, F. E. 2004. Potential Prunus host range of PPV-PENN isolates by aphid transmission. Acta Hortic. 657:201-205.

Wallis, C. 2004. Aphid vectors and viral microevolution of Pennsylvanian strains of plum pox virus. M.S. thesis, The Pennsylvania State University, University Park, PA

Damsteegt, V.D., Stone, A.L., Sherman, D.J., Schneider, W.L., Gildow, F., Luster, D.G. 2005. *in Planta* Interactions of Three Plum Pox Potyvirus Strains Within Cultivar Lovell Peach Seedlings[abstract]. Phytopathology. 95:s22.

VII. Fruit Grower Observations and Recommendations

There was an informal meeting of the growers who were most affected by the PPV eradication program in May 2006 to discuss their view of the PPV eradication project. These growers included the grower and his brother who first observed PPV in their orchard and the grower who was the president of the PA state fruit grower organization when PPV was first identified as a problem. Both growers lost all of their peach, nectarine and apricot orchards totaling nearly 500 acres. At the time of the interview, neither grower was permitted to replant any stone fruits on their farm since the eradication began nearly 7 years earlier. The discussion and this summary were facilitated by a local extension educator and a state extension specialist who had worked along side the growers since the beginning of the PPV eradication program.

The growers were in agreement that the PDA, USDA and Penn State University personnel they interacted with over the course of the PPV eradication effort have been responsive and supportive. There was particularly high praise for the efforts of the PDA and Penn State extension for the dedication of time and effort extended in their behalf as the PPV situation unfolded in 1999 and 2000. There was good communication at the onset of the PPV eradication program and regular communication has continued as the program has advanced to keep them informed and involved in the process.
The regular communication meetings between growers, government regulators, legislators and extension have been appreciated by the fruit grower community. These meetings are continuing with the most recent, at the time of writing this report, held in May of 2006.

The growers agreed that new science based information developed by PSU and USDA scientists have provided answers to some important questions regarding spread and containment of PPV. Quarantine and eradication decisions made by PDA and the USDA have been based on the best science available. The support of PSU ag economists in working with the USDA to develop the indemnity program and the financial support provided through local legislators and PDA were instrumental in assuring grower cooperation and the ultimate success of the PPV eradication program.

Grower suggestions for successful completion of the PPV eradication effort.

Grower PPV Funding Issues and Recommendations:

1. Issue: There is concern in the grower community that the federal government will stop or significantly reduce the support funds for PPV eradication before successful completion of the PPV eradication program. This will make useless all the grower sacrifice and PPV eradication efforts that have taken place to date.
   Recommendation: The federal and state government should approve full funding to complete PPV eradication, with a reduced but adequate funding for surveillance, monitoring and education by PDA, USDA and PSU extension for another 10 years thereafter. Volunteer grower monitoring for PPV will not be effective.
2. Issue: Currently USDA funding to compensate growers who have received government orders for removal of their orchards is considered on a year to year basis following tree removal. This has resulted in the approval decision for compensation and payment being delayed longer than one year after the orchards have been removed by the grower with no assurance that they will be compensated. This is the current situation in 2006.
   Recommendation: Put in place long term PPV compensation funding mechanisms to remove the uncertainty of compensation funding to growers.
3. Issue: For the future when the PPV eradication program is successfully completed, funding to compensate fruit growers for catastrophic events such as re-introduction of an invasion species or unusual weather events resulting in crop loss and reduced profitability is needed.
   Recommendation: Put in-place long-term funding mechanisms such as crop insurance to deal with catastrophic weather and biological/ecological events.

Grower PPV Eradication Issues and Recommendations:

4. Issue: Initially growers were very involved in the decision –making process but as time has gone on they have become the recipients of decisions made by PDA and USDA without significant opportunity for input.
   Recommendation: Incorporate the growers and PSU extension back into the decision making process.
5. Issue: Growers with orchards located in a quarantine zone but who did not have their orchard removed have suffered the most. They have not been permitted to follow normal production practices such as replanting to maintain full orchard productivity.
   Recommendation: Allow growers to replant in existing orchards ina quarantine zone with ‘clean’ planting material to maintain orchard productivity.
6. Issue: Removal of quarantine zones and removal of commercial orchards have been delayed due to a delay in testing and detection of positive PPV plants on homeowner properties inside the quarantine zone.
   Recommendation: Eradicate all susceptible hosts from homeowner properties at the time the quarantine zone is initially established.

VIII. Mitigation and Disease Management

Prevention

It is important to prevent the spread of PPV in propagation material. This is accomplished through the use by nurseries of virus indexed plant material that is certified to be tested for the virus. The US Department of Agriculture and state departments of agriculture utilize laboratory procedures to test for several viruses including PPV and certify that the stone fruit plant material can be used by nurseries for propagation.

While importation of nursery material into the United States is regulated, infrastructure for testing and certification of imported material is not being fully supported and could result in more introductions of PPV or other serious viral diseases. In addition, any screening of domestic stock is currently voluntary. Programs to monitor domestic material, in the event that an introduction occurs, is critical and is not provided for beyond the emergency/eradication program.

Management

Management of PPV will become necessary if prevention and eradication efforts fail due to the spread of the disease in stone fruit orchards or native 'wild' stone fruit hosts. If the disease becomes established in stone fruit trees it will be managed through regular orchard surveys and tree removal if individual trees are found to be infected. Surveys will be conducted in the spring when visual symptoms are most apparent. Tissue samples may also be collected at this time to verify PPV infection using laboratory analysis. Individual trees will be removed when only a few trees are found to be infected in an orchard. Orchard removal will occur once significant numbers of the trees in an orchard are found to be infected with PPV. For example, one PPV management program in Europe removes the entire orchard if more than 10% of the trees are found to be infected with PPV.

Aphid management through the use of insecticides is not expected to be effective in reducing the spread of PPV in stone fruit orchards. Aphids that visit a healthy stone fruit tree can transmit PPV to the tree through feeding before the insecticide affects the aphid. Tree removal begins with cutting of infected trees in the orchard. Some specialists suggest that applying an insecticide to the infected stone fruit tree a day or two prior to cutting may prevent aphids from spreading the virus as they fly from the wilting infected tree to healthy trees in the orchard.

Weeds have not been found to serve as hosts for PPV. It will be important to eliminate native stone fruit trees near commercial stone fruit orchards.

Genetically Resistant Cultivars

Genetic resistance to the plum pox virus have been identified and transferred to 'HoneySweet' plum. The plum was developed at the USDA-ARS research facility in West Virginia. This is the first stone fruit cultivar developed for resistance to the plum pox virus. The USDA-ARS petitioned the USDA Animal and Plant Health Inspection

Service in 2004, to non-regulate the 'HoneySweet' plum which is one of the first steps in commercialization. The fruit yield, quality and market value under a range of growing and cultural conditions remains to be determined. Stone fruit cultivars resistant to PPV hold the most promise in managing PPV in the future if eradication efforts fail. However there is considerable debate about consumer and commercial acceptance of the new plum pox resistant cultivar. The 'HoneySweet' plum is currently not available for commercial use.

IX. Current Infrastructure Needs

The following suggestions were made throughout the course of compiling this document to improve infrastructure.

- Enhance infrastructure of importation stations.
- Enhance the national clean stock program.
- Make quarantine pest research facilities available, at a regional level.
- Make flexible laboratory space available for overflow/surge testing capacity at a regional level.

X. Research, Extension and Education Priorities

1. Pathways: A stronger *Prunus* industry would emerge from this crisis if steps are taken now to prevent introduction of such a pest again. Given the relatively new division of duties at the ports between Homeland Security and USDA officers, a fresh look into pathways of entry of *Prunus* material into the U.S., and mechanisms to detect or monitor for new introductions. Stakeholders need to look at existing nursery importation, clean stock, and certification structures, and improve them where necessary. The industry as a whole should also look at industry practices with fruit, and modify sanitation to decrease the risk of transmission of virus to new areas through aphid transmission from infected fruit to healthy trees.

2. Research into plum pox expression and detection in climates like California or other high-temperature areas should continue to occur to make certain that monitoring tools used there are appropriate.

3. Validation of new detection reagents and technologies remains important to be certain that the best detection tools are being used in the eradication program and in future monitoring schemes. In addition, a proactive approach should be taken to identify and develop monitoring strategies for other exotic pests that have economic impacts on the same scale as plum pox virus.

4. With various "cherry" types, including some species common to wooded areas in Pennsylvania, being identified as potentially susceptible to the PA-isolate of PPV by ARS and PSU workers at Ft. Detrick, vigilance is needed to insure that plum pox does not become established in a wild setting where control is less feasible. Research to

understand the potential for cherry to be an epidemiological component of disease spread is needed.

5. General work on the pattern of disease spread in PA and Ontario, and epidemiological comparisons of the two programs, could help us predict the chances of success, or predict where to concentrate our energy in the search for remaining virus.